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Estimation of NDVI Calculation Error When Using Empirical Methods for Atmospheric Correction

K.I. Zubkova, T.G. Kurevleva, L.I. Permitina[1]

[1] *candidate of engineering science*
Joint Stock Company "Russian Space Systems", Russia

e-mail: zubkova.k@ntsomz.ru

Abstract. The paper presents the results of the analysis of different empirical atmospheric correction method applicability to the Resurs-P spacecraft hyperspectral data for the NDVI calculation. The methods such as FF (Flat Field), DOS (Dark Object Subtraction), DOS-1% (Improved Dark Object Subtraction) and COST (Cosine Approximation Model with atmospheric transmittance taken into account), as well as the atmospherically corrected value calculation using the Lambert's formula, are considered and used. The paper analyses the merits and drawbacks of each method. It is concluded that the empirical methods taking into account the atmospheric effects improve the NDVI calculation accuracy. The atmospheric correction effect of DOS1-% and COST is the best; the mean deviation values do not exceed 5%. The results obtained in this study may be applied for solving the problems requiring the knowledge of underlying surface spectral radiance factors.

Keywords: Earth remote sensing, atmospheric correction, hyperspectrometer, spectral radiance, NDVI

Introduction

To solve the tasks of the Earth remote sensing (ERS), it is necessary to know the spectral brightness factors (SBF) of the underlying surface calculated according to radiometrically calibrated data allowing for the atmospheric influence. Accurate atmospheric correction of the ERS data in majority of cases is impossible due to the lack of a complete set of the necessary atmospheric parameters. Thus, many methods for empirical atmospheric correction have been developed.

The paper gives the analysis results for applicability of the following methods: DOS (Dark Object Subtraction), COST (Cosine of the Solar Zenith Angle, COS (TZ)), Flat Field, and so on [1, 2, 3] for hyperspectral data received from the Russian spacecraft (SC) Resurs-P No.No. 1, 2.

Methods of empirical atmospheric correction

1. ***Flat Field***. A method implies a reference object, for which SBF is known a priory. A reference spectrum for correction is determined as averaged values of spectral density of energy brightness (SDEB) on the uniform surface area of the reference object. SBF in each pixel with the coordinates (i, j) is determined in the form of (1):

$$\varrho_{i,j} = \frac{L_{i,j}}{L_{i,j}^{prot}} \times \varrho_{i,j}^{ref} \quad (1)$$

where is the SDEB on the upper boarder of the atmosphere (UBA), is the average spectrum of SDEB on UBA of the reference object, is the SBF on UBA of the reference object.

A prototype area should have the following characteristics:

1. A surface area should be flat (near to the Lambert one) for the correct averaging of the SDEB values.

2. A surface area should be bright (for example, a light-colored sand) to increase a signal-to-noise ratio.

2. ***Lambertian Reflectance*** (calculation by the Lambert formula). In this method, calculation of SBF is carried out by the formula for the Lambertian surface (2):

$$\varrho_k = \frac{\pi L_k}{S_k \cos \Theta_S} \quad (2)$$

where is the SDEB on SBF, is the SBF on UBA,is the solar constant (solar irradiation on UBA within the limits of the function of the channel spectral sensitivity к), and is the zenith angle of the Sun.

The method is applied at the complete absence of knowledge on the atmosphere under the area of interest [4].

3. ***DOS*** (subtraction of "the dark background"). The method is for recording the atmospheric haze. A value of a dark object on the underlying surface is taken as the value of SDEB of the haze. The haze value is subtracted from SDEB to UBA, and than calculation of SBF onto UBA by the formula (3):

$$\varrho_k = \frac{\pi(L_k - L_{dark})}{S_k \cos \Theta_S} \quad (3)$$

where is the SDEB onto UBA, is the UBA onto SBF,is the solar constant for the channel *k*, is the zenith angle of the Sun, and is the SDEB of the dark object.

4. ***Modified DOS***. The DOS method [4, 5] suggests that there are no reflections from the object, but the energy got by the pupil of the target equipment is due to the presence of the atmospheric haze. However, in later works dedicated to the atmospheric correction, the SBF of the dark object is not considered equal to zero, and the value of the atmospheric haze is calculated as the difference between SDEB of the dark object and SDEB corresponding to 1–2% from SDEB of the dark object. After subtraction of the haze influence, the calculation of SBF onto UBA is carried out by the formula (4) [4]:

$$\varrho_k = \frac{\pi(L_k - L_{1\%})}{S_k \cos \Theta_S} \quad (4)$$

where $L_{1\%} = \frac{0.01 * S_k \cos \Theta_S}{\pi}$ (5)

where is the SDEB onto UBA, is the UBA onto SBF, is the solar constant, is the zenith angle of the Sun, and is the SDEB of the dark object.

5. ***COST***. In this method, an atmospheric haze is calculated the same way as in the "Modified DOS" method. However, apart from considering the atmospheric haze, the method suggests an empirical record of the atmosphere transparency [4]. The transparency factor of the atmosphere is calculated as the cosines of the zenith angle of the Sun and the cosines of the zenith surveillance angle from the spacecraft. Primary, the method was used only for the data of the survey in the nadir [4], that is why only the cosines of the zenith angle of the Sun (a cosines of the viewing angle equals to 1) was taken into account.

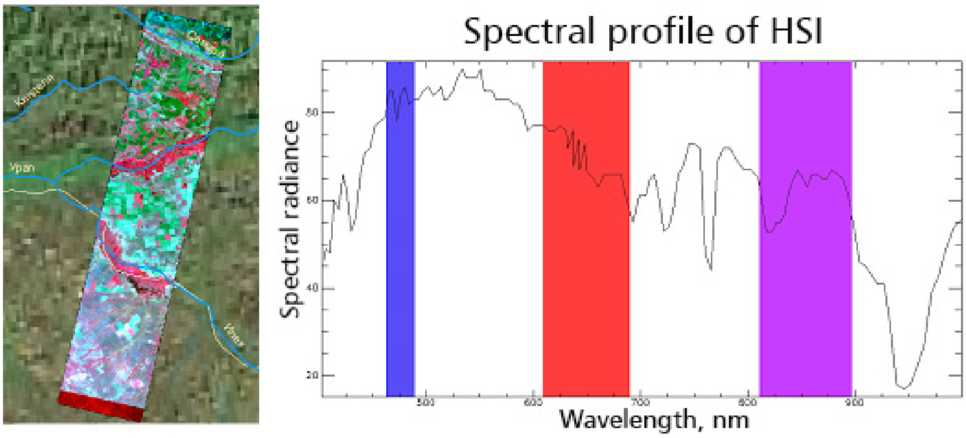

Fig. 1. The survey data the HSE (hyperspectral equipment)/Resurs-P No. 1. A synthesis of the channels 106 (859 nm), 60 (636 nm), 40 (550 nm) (on the left) and the spectrum of the central point of the hyperspectral survey (on the right).

Nowadays calculation of SBF is made by the formula (6):

$$\varrho_k = \frac{\pi(L_k - L_{1\%})}{S_k \cos^2 \Theta_s \cos\Theta_{viz}} \quad (6)$$

where is the SDEB onto UBA, is the SBF onto UBA,is the solar constant for the channel *k* under analysis, is the zenith angle of the Sun, is the SDEB of the dark object, and is the cosines of the viewing angle.

Description of the input data for research

The research has been carried out based on the data of the hyperspectral survey of the spacecraft Resurs-P No. 1 dated May 16, 2014, 10:27 Decreed Moscow Time (07:27 UTC) of the territory of the Orenburg region and the data of the survey MODIS of the Terra spacecraft dated May 18, 2014, 07:45 UTC (Fig. 1).

The survey data are visualized in pseudocolors, vegetation is shown in red, and soil is in blue that is due to the combination of the chosen channels: near infrared, red, and blue.

Crosscalibration of the data

Since there are problems with radiometric calibration of hyperspectral data [6], it was not possible to study the methods of atmosphere correction based on narrow band indices.

Estimation of NDVI calculation error was made based on the wide band NDVI through the operation with wide spectral ranges formed by means of averaging the hyperspectral ranges into three spectral ranges corresponding to the functions of spectral sensitivity of the channels 3, 2, 1 of the MODIS equipment (Fig. 1).

To obtain a correct value of SDEB onto UBA, radiometric crosscalibration of the HSE data according to the MODIS data (in the form of the MOD02 product – the data on SDEB of the underlying surface) was carried out. After spatial data combination, building of 100 test facilities on the similar surface area was performed. Moreover, average values of SDEB of HSA and MODIS for each of the test sites was made. Crosscalibration was made by the formula (7):

$$L_R = L_M \; \frac{S_R}{S_M} \; \frac{\cos \Theta_{sR}}{\cos \Theta_{sM}} \quad (7)$$

where , are the SDEB of MODIS and HAS respectively, is the ratio of solar constants (Exoatmospheric Solar Irradiance) for a pair of the channels taking into account the width and form of the functions of spectral sensitivity of the channels of HSE and MODIS, and is the ratio of the cosines of the zenith angle of the Sun during the survey allowing for survey asynchrony.

Fig. 2 shows the crosscalibration results: the *x* axis carries the values of SDEB of HSE, the *y* axis has the values of SDEB of MODIS lead to the survey conditions of HSE. Based on the crosscalibration results, correction of the SDEB values in the averaged blue, red, and near infrared channels of HSE was carried out. A calibration function corresponding to the SDEB scaling for each of the three channels is given in the upper part of each graph. Further, only the calibrated HSE data were used.

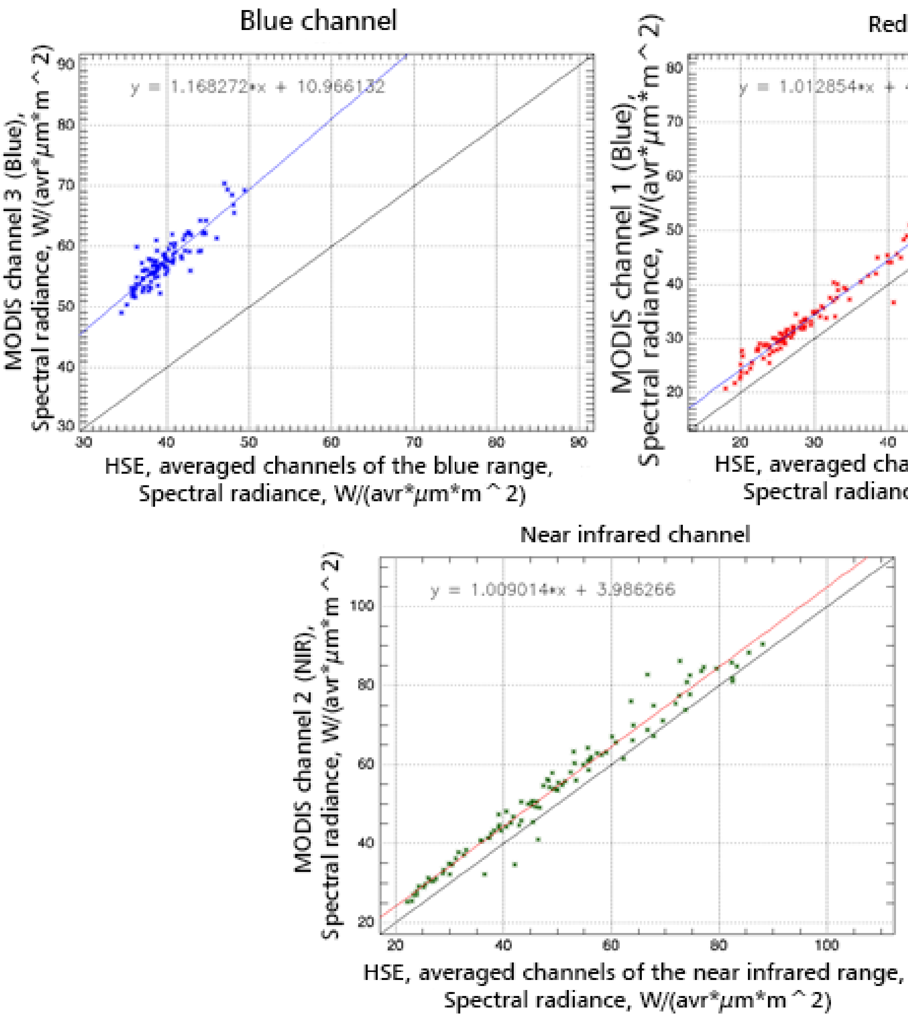

Fig. 2. Comparison of the SDEB values of the averaged HSE channels/Resurs-P No. **1** (*x* axis) and SDEB MODIS of the Terra spacecraft (*y* axis) lead to the conditions of the HSE survey.

Atmospheric data correction

Atmospheric correction of the averaged HSE channels is carried out after crosscalibration through a software package 6S taking into account the following parameters:

1. A model of the atmosphere is a user one requiring an input of the value of a total content of vapor (2.20 g/cm^2) and a total content of ozone (356 DU). The data are obtained from the product MOD09 of MODIS.

2. A model of the atmospheric aerosol is continental; a content of aerosol on the wavelength of 550 nm (according to the 6S requirement) is obtained according to the data of the nearest AERONET station in Yekaterinburg (AOT = 0.13, AOT (Aerosol Optical Depth of the atmosphere).

3. An average altitude of the underlying surface above the sea level is 120 m.

NDVI calculation

After atmospheric correction, NDVI calculation was performed. Its values became a standard when evaluating the NDVI calculation error by empirical methods.

Fig. 3 gives the comparison result of the NDVI values calculated by empirical methods, with the standard – the NDVI values calculated after crosscalibration and atmospheric correction of the HSE data. As during crosscalibration, comparison of NDVI in the form of scattergrams is made for the average NDVI values on each of 100 test facilities. The graph carries the NDVI values calculated by the formula (2).

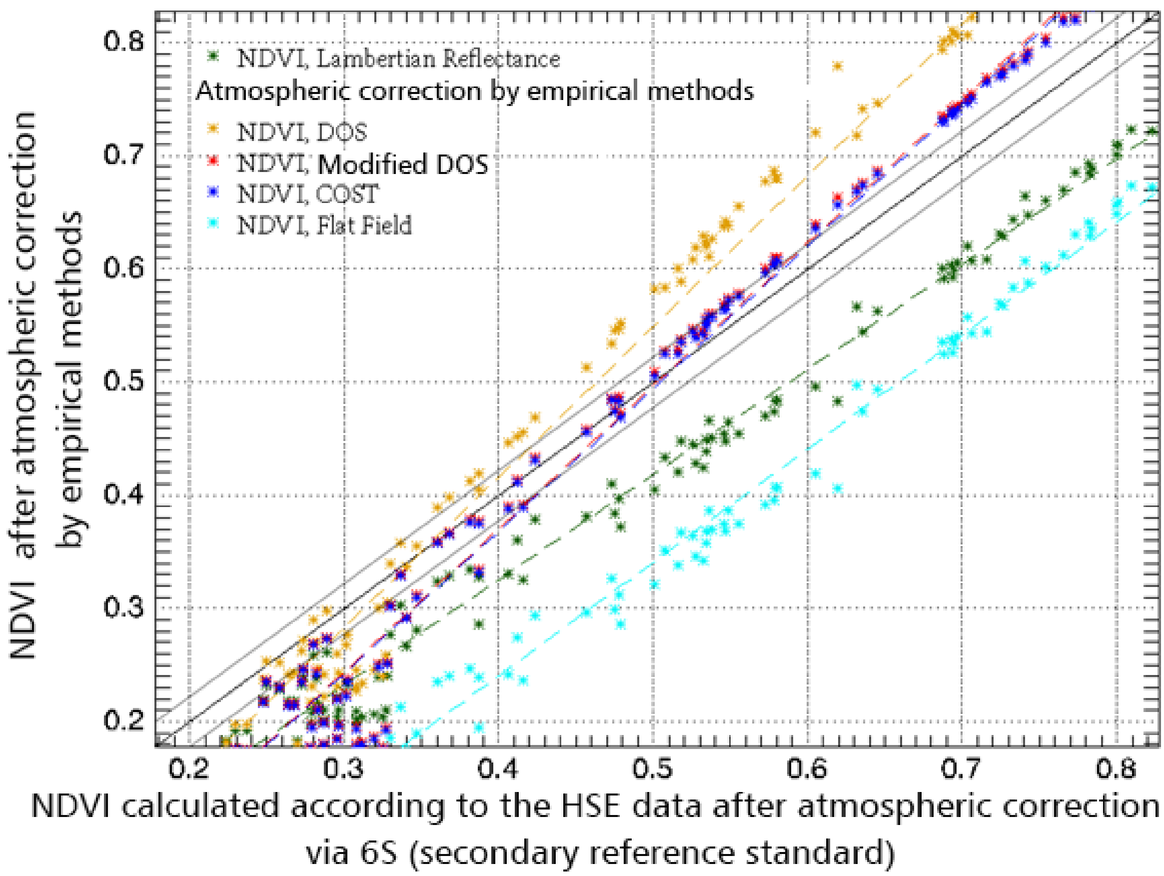

Fig. 3. Comparison of the NDVI calculated after the atmospheric correction by empirical methods with a reference object.

Ideally, the scatterogram of the NDVI values should lie squarely at angle 45° (along the black line). The results of the analysis have shown that a modified DOS method gives the minimum deviation from the reference object. In particular, an average deviation from the prototype does not exceed 2% in the range of the NDVI values from 0.3 to 0.6. In the method "Modified DOS", the value of the atmospheric haze is less than in the DOS method. Hence, overcorrection of the SBF values has a not so explicit effect; it is noticeable only for the small (up to 0.3) NDVI values.

In the COST method, an atmospheric fog is calculated the same way as in the method "Modified DOS". The transparency of the atmosphere is calculated as cosines of the zenith angle and does not depend on the wavelength. Therefore, the COST method does not give additional information into the NDVI method in comparison with the "Modified DOS" method: a constant value of the transparency of the atmosphere decreases.

Great deviations from the reference values (not less than 20%) make it possible to calculate NDVI according to the Lambertian Reflectance method. However, the DOS method also results in a great relative deviation. This happens because in the nearest IR channel, the DOS method leads to overcorrection of the SBF values: an atmospheric haze is significantly less than that of in the red channel and in the SDEB value being deducted; along with an atmospheric haze, it has a part of the "useful" solar energy reflected from the surface.

Using the Flat Field method resulted in deviation from the NDVI reference object more than 30%. First of all, is can be due to the incorrect choice of the reference spectrum Q_{ref} from the soils.sli library prepared by the Johns Hopkins University (Brown loamy fine sand, Hapulstalf 87P3468): a test site with a dry soil the spectrum of which was further compared with the spectrum of the dry soil after atmospheric correction of the HSE data was chosen for the analysis. Under such conditions, an average deviation does not depend on the NDVI value compared to the "Modified DOS" method.

Table below gives the values of the average deviation from the reference object for each of the methods of the empirical atmosphere correction.

Table. The values of the average deviation from the reference object for each of the methods of the empirical atmosphere correction

A method's name	A value of the average deviation
Lambertian reflectance	> 20%
DOS	10–15%
Modified DOS	In the range from 0.3 to 0.6 – 3%, in other intervals – 5%
COST	In the range from 0.3 to 0.6 – 3%, in other intervals – 5%
Flat Field	> 30%

Conclusion

In the course of work, the areas where the empirical methods of the atmosphere influence during the processing of the hyperspectral ERS data based on the evaluation of the NDVI error were determined.

The results obtained can conclude the following:

1. Using the empirical methods of the atmosphere correction results in decrease in evaluating of the NDVI error in comparison to the calculation without the atmosphere correction. The results with the least deviation are obtained employing the "Modified DOS" method, where the calculation of the atmospheric haze is performed using a "dark" object with the deduction of SDEB corresponding to SBF of the object 0.01. In the range of the NDVI values from 0.3 to 0.6, the deviation of the NDVI calculation is in the range of 0.02 that corresponds to the nominal value of the error for the MOD13Q MODIS product containing the composites of the NDVI values during 10 days.

2. The COST method gives the same results as the "Modified DOS" method because reducing a constant influence of the atmosphere.

3. The largest average deviation from the reference object calculated by means of 6S demonstrated the Flat Field method. The disadvantages of the Flat Field method is that an operator has to choose the above-mentioned object. Moreover, the method is not useful for the area of the underlying surface containing only vegetation. However, it can be employed for the analysis of the territories of urban settlements, roads, and concrete structures. "Employed" in this context means "using this method leads the hyperspectral data to the most convenient view and greatly increases the calculation accuracy of the NDVI" [4]. During comparison of the spectra with true values of the measurements on the area, the errors of the atmospheric correction can be too large (more than 30%).

4. Additional correction of the SBF occurred when using the DOS method because of the deduction of the "useful" information during processing along with the atmospheric influence. In the region of the high NDVI values (more than 0.4), an average deviation from the reference object was about 20%.

The best results were achieved using the "Modified DOS" and COST methods. Their application is limited by the fact that "dark" objects (water areas, heavy vegetation or strongly shaded regions) should be present on the underlying surface of the "dark" objects.

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